FNAL-Homestake Beam Design - Targeting studies

EuroNu Targeting Meeting, CERN 12/16/08

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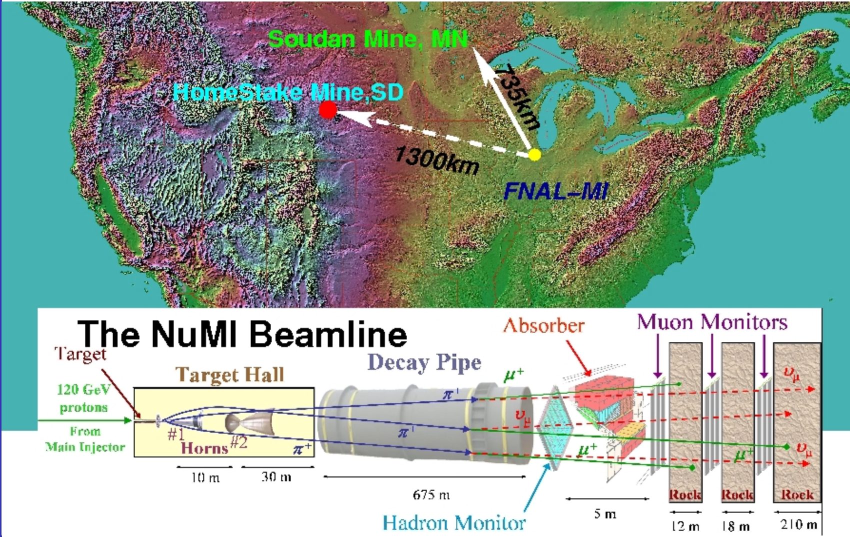
December 15, 2008

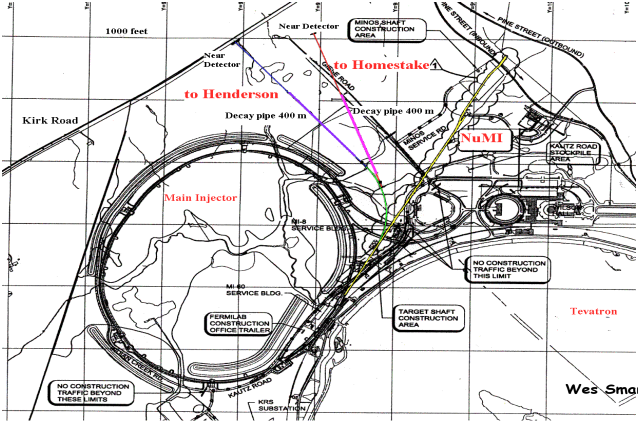
Outline

BROOKHAVEN NATIONAL LABORATORY

Neutrino Beamlines at FNAL



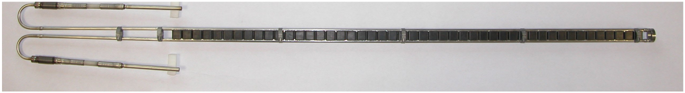
Layout of the NuMI/Hstake beam



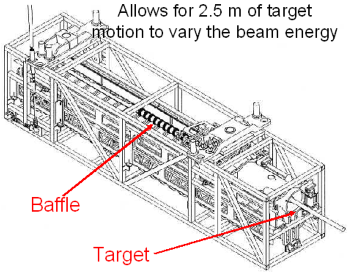
Current design is to use the NuMI extraction and carrier tunnel down into the good rock near the NuMI target hall, then direct the proton beam down a new tunnel towards Homestake.

Can accomodate decay pipe lengths of up to 600m

NuMI/MINOS Target



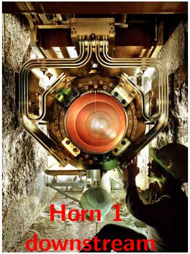
Graphite segmented target: 47 fins each fin is 6.4mm in width, 18mm in height and 20mm long. Density is 1.784 g/cm^3. Mounted in a movable carrier system. In low energy position, target is inserted 45cm into horn1.



Target 1 replaced in Fall '06 due to failure of movable carrier (1.4E20 protons integrated dose). Target 2 recieved 4.6E20 protons so far. Some preliminary evidence of radiation damage has been observed in Target 2.

NuMI/Hstake CPV sensitivity requires $\geq$ 60E20 p.o.t at 120 GeV (6 MW.yr)

NuMI/MINOS Horns



Al parabolic focusing horns, operating at 185-200kA (10μ s pulse). 3T field at 200kA.

Water cooled. 5 failures in ceramic transitions in water cooling lines so far

June 3-July 15 '08: Horn 1 suction line failed - horn replaced.

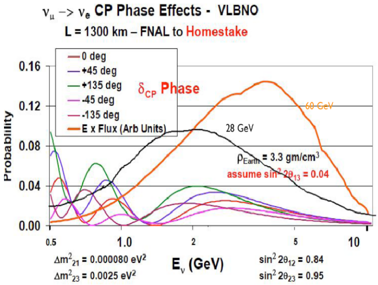
Nov 17-Dec 11 '08: Horn 2 strip line failure - horn replaced

> 22 million pulses with first horn 1

> 25 million pulses with first horn 2

Requirements of the FNAL/Homestake Beam

The design specifications of a new WBLE beam based at the Fermilab MI are driven by the physics of $\nu_\mu \rightarrow \nu_e$ oscillations:



L = 1300 km

Requirements:

-Maximal possible neutrino fluxes to encompass the 1st and 2nd oscillation nodes, with maxima at 2.4 and 0.8 GeV.

Getting enough flux at both nodes is critical to CPV sensitivity

-High purity ν_μ beam with negligible ν_e.

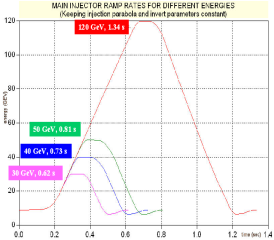
$\sin^2(2\theta_{13}) = 0.005 \Rightarrow$
$P(\nu_\mu \rightarrow \nu_e) \sim 0.3\%$.

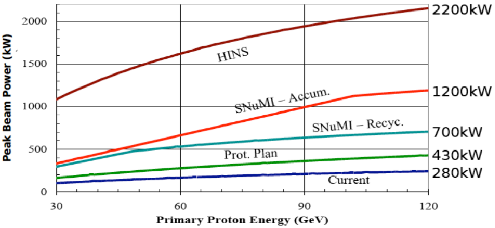
-Minimize the neutral-current feed-down contamination at lower energy, therefore minimizing the flux of neutrinos with energies greater than 5 GeV where there is no sensitivity to the oscillation parameters is highly desirable.

Present/Future proton beam options from FNAL

ANU(SNuMI): **Use the recycler (and anti-proton accumulator?) to store protons from the 8 GeV 15 Hz Booster during the MI cycle then inject to MI $\rightarrow$ increases MI intensity up to 6×10^{13} protons $\Rightarrow$ 0.7 (1.2) MW at 120 GeV.**

HINS a.k.a Project X: **S.C. Linac replaces 8 GeV Booster, MI upgrades $\Rightarrow$ 2.2MW at 120GeV**

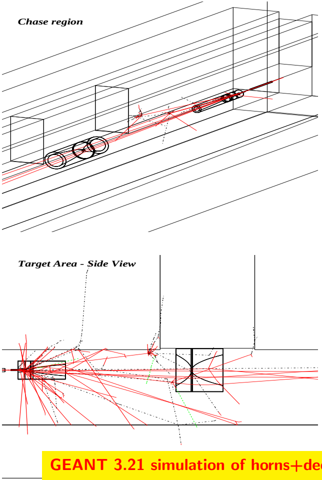




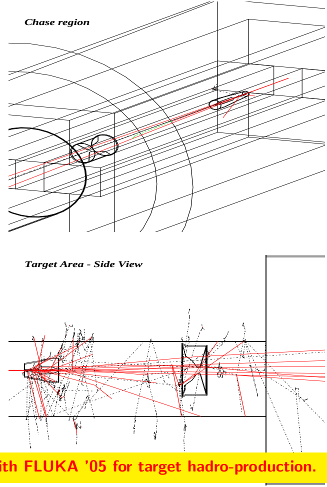
CHALLENGE: Can we use a 120 GeV beam to produce a low energy wide-band neutrino beam for megaton detectors at Hstake?

Example of a DUSEL beam simulation (120 GeV)

NuMI horns/target



AGS horns and embedded target

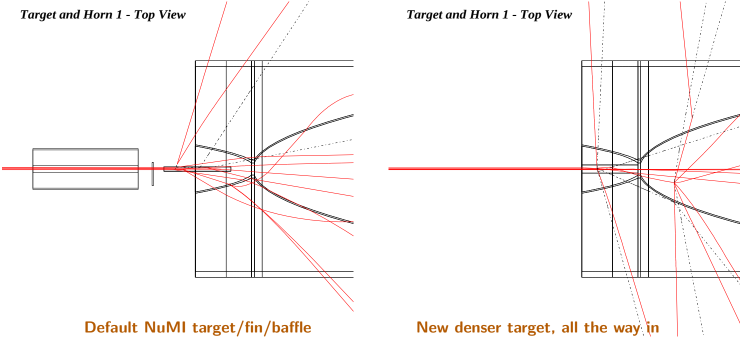


GEANT 3.21 simulation of horns+decay pipe, with FLUKA '05 for target hadro-production.

Latest target/focusing system design

GOAL: Optimize focusing and decay pipe size for 120 GeV beam using NuMI-like horns . NB: We found the AGS horn design works best at $<$ 60 GeV

Insert CC target (r=6mm,L=80cm,$\rho = 2.1$ g/cm^3) into NuMI Horn1, increase current to 250kA:

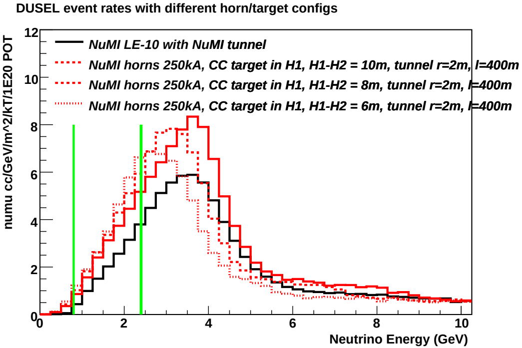


Default NuMI target/fin/baffle

New denser target, all the way in

Optimizing DUSEL spectra with NuMI horns

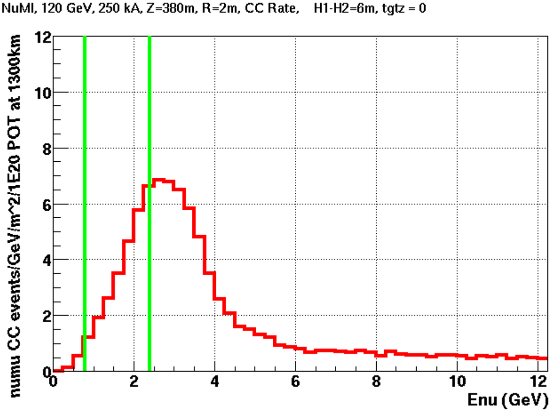
1-Decrease separation between Horn1 and Horn2



Optimizing default NuMI horn configuration with an embedded target and a wider decay pipe produces an on-axis flux compatible with a WCe DUSEL detector

Are embedded targets necessary?

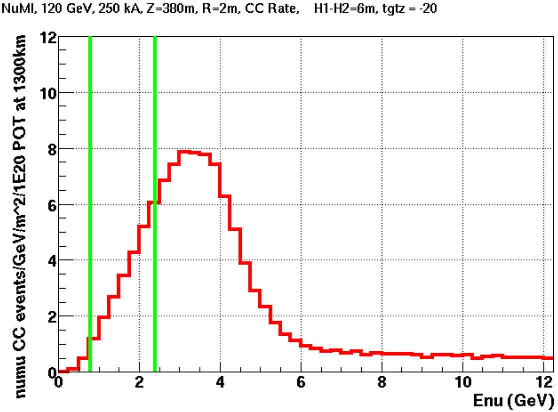
2- Target position in Horn 1. H1-H2 = 6m



Target fully embedded in horn

Are embedded targets necessary?

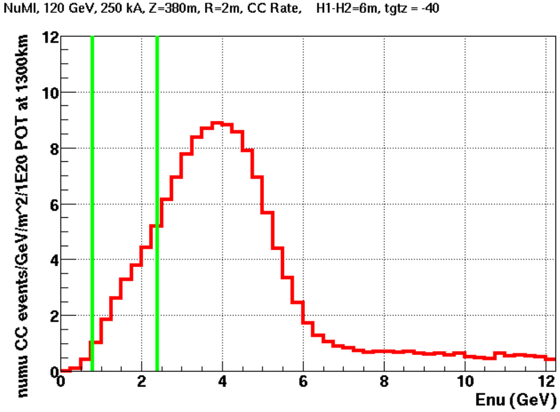
2- Target position in Horn 1. H1-H2 = 6m



Target pulled out 20cm from Horn 1 face

Are embedded targets necessary?

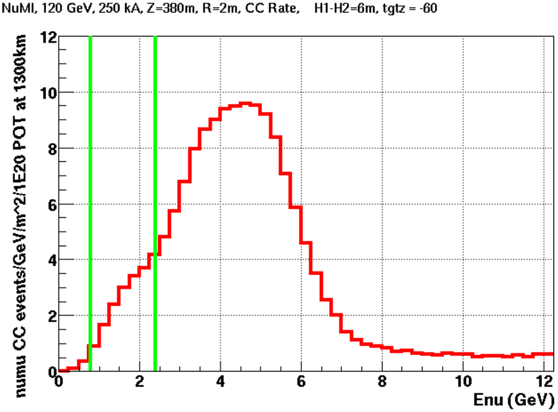
2- Target position in Horn 1. H1-H2 = 6m



Target pulled out 40cm from Horn 1 face

Are embedded targets necessary?

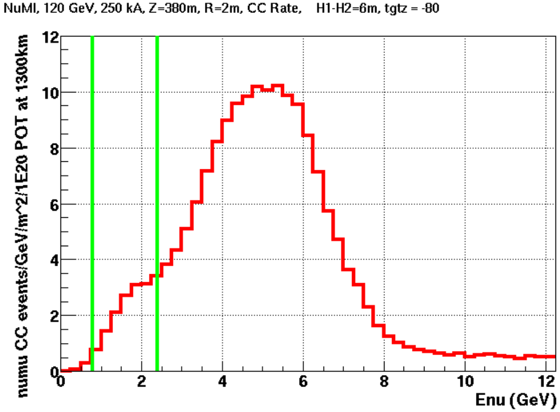
2- Target position in Horn 1. H1-H2 = 6m



Target pulled out 60cm from Horn 1 face

Are embedded targets necessary?

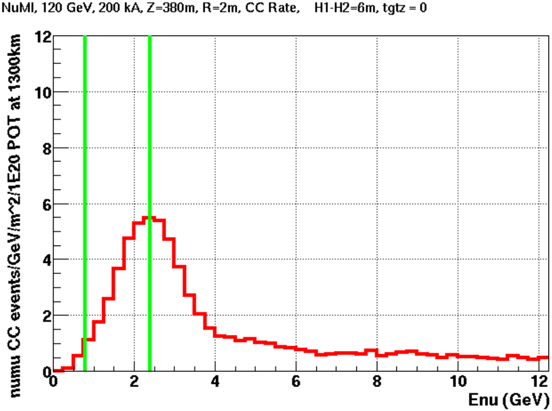
2- Target position in Horn 1. H1-H2 = 6m



Target pulled out 80cm from Horn 1 face

Horn current requirements

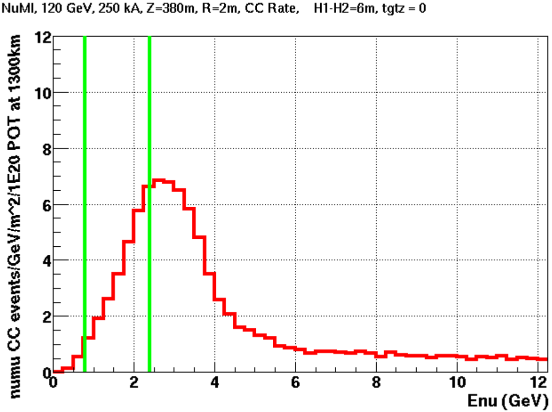
3- Optimize horn currents for DUSEL.



Target fully embedded in horn - 200kA

Horn current requirements

3- Optimize horn currents for DUSEL.



Target fully embedded in horn - 250kA

Horn current requirements

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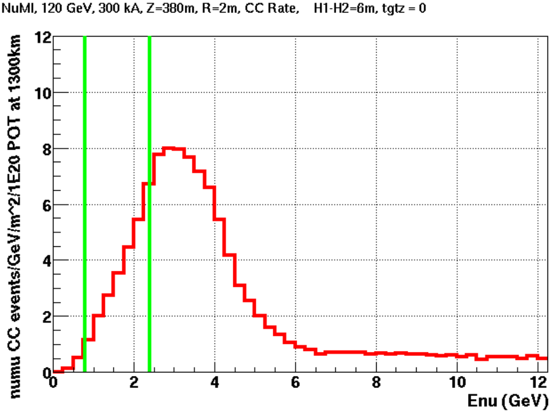
NuMI/Hstake Designs

Event rates and sensitivities

Summary and Plans

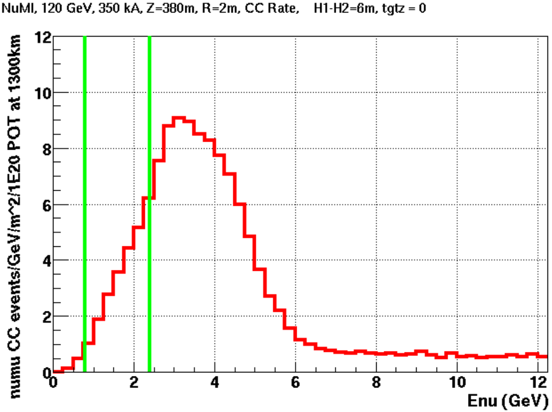
3- Optimize horn currents for DUSEL.



Target fully embedded in horn - 300kA

Horn current requirements

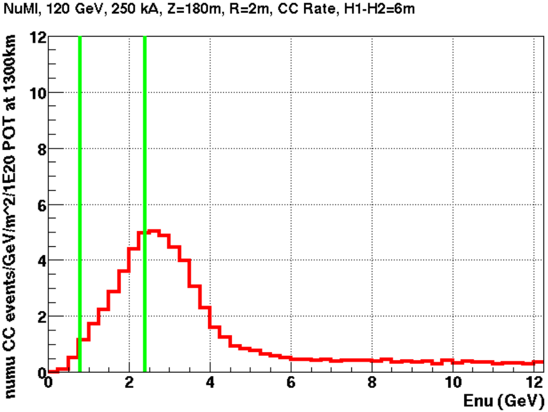
3- Optimize horn currents for DUSEL.



Target fully embedded in horn - 350kA

Optimizing the decay pipe length

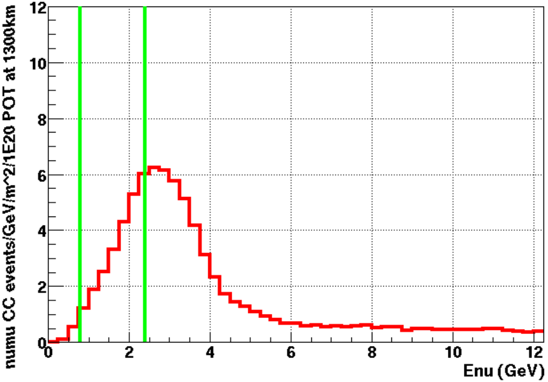
4- Biggest cost driver - how small a volume can we use?



Decay pipe length = 180m

Optimizing the decay pipe length

4- Biggest cost driver - how small a volume can we use?



Decay pipe length = 280m

Optimizing the decay pipe length

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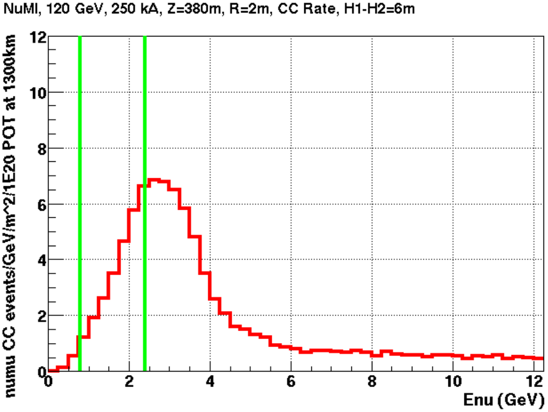
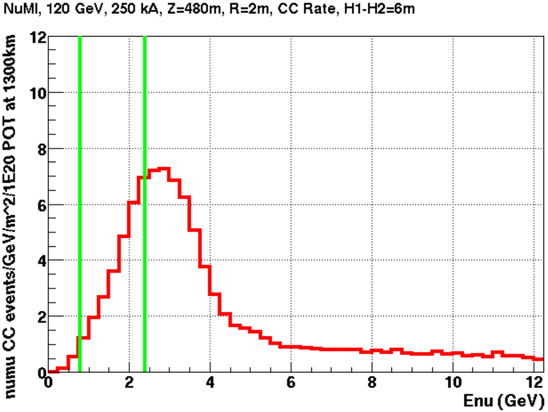
4- Biggest cost driver - how small a volume can we use?



Decay pipe length = 380m

Optimizing the decay pipe length

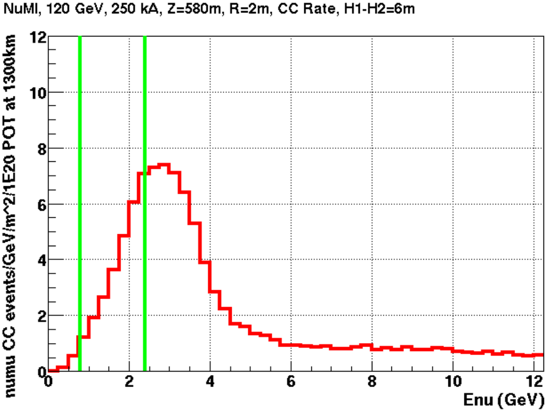
4- Biggest cost driver - how small a volume can we use?



Decay pipe length = 480m

Optimizing the decay pipe length

4- Biggest cost driver - how small a volume can we use?



Decay pipe length = 580m

Physics Sensitivities

Physics sensitivity with WCe, 3σ for all δ_{cp} (θ_{13}, hier)/50% δ_{cp} (CPV)

Beam	Det size (FIDUCIAL)	Exposure $\nu + \bar{\nu}$	bkgd uncert	$\sin^2 2\theta_{13}$	sign(Δm^2_{31})	CPV
NuMI/HStake	100kT	700kW 2.6+2.6yrs	5%	0.018	0.044	> 0.1
120 GeV	100kT	1MW 3+3yrs	5%	0.014	0.031	> 0.1
9mrad off-axis	300kT	1MW 3+3yrs	5%	0.008	0.017	0.025
	300kT	1MW 3+3yrs	10%	0.009	0.018	0.036
	300kT	2MW 3+3yrs	5%	0.005	0.012	0.012
	300kT	2MW 3+3yrs	10%	0.006	0.013	0.015

NB: Flux at 1st oscillation maximum has increased by 25% since these calculations

Summary and Plans

- **Decay pipe lengths between 300-400m are sufficient with radius = 2m. Optimization of shape to control civil construction costs without compromising physics reach is CRITICAL**
- **Very preliminary studies in optimizing the focusing system for the DUSEL beamline using 120 GeV beam have demonstrated:**
  - **NuMI horns without modification + thicker denser embedded target in horn 1 can produce an ON-AXIS beam that will work with WCe.**
  - **With an embedded target, Horn currents of 250-300kA are the most optimal.**
- **Still having trouble getting enough flux at 1GeV. Some ideas:**
  - **We can lower the beam energy to $\sim$ 100 GeV without much loss of power.**
  - **Small gains are still possible with horn/target configuration and target material and geometry.**

BACKUP

Raw event rates

Unoscillated ν_μ rates at 1300km:

120 GeV on-axis: 20,000 CC/MW.100kT.10^7, 9mrad off-axis: 9,000 CC/MW.100 kT.10^7s

60 GeV on-axis: 15,000 CC/MW.100kT.10^7s

Oscillated rates at 1300km:

(sign of Δm^2_{31})	$\sin^2 2\theta_{13}$	$\nu_\mu \rightarrow \nu_e$ rate				$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ rates			
		δ_{CP} deg.							
		0°	-90°	180°	+90°	0°	-90°	180°	+90°
WBLE beams at 1300km, per 100kT. MW. 10^7s									
120 GeV, 9 mRad off-axis		Beam ν_e = 47**				Beam $\bar{\nu}_e$ = 17**			
(+/-)	0.0	14	N/A	N/A	N/A	5.0	N/A	N/A	N/A
(+)	0.02	87	134	95	48	20	7.2	15	27
(-)	0.02	39	72	51	19	38	19	33	52
60 GeV, on-axis		Beam ν_e = 61**				Beam $\bar{\nu}_e$ = 22**			
(+)	0.02	138	189	125	74	30	12	19	37
(-)	0.02	57	108	86	34	46	27	48	67

$\Delta m^2_{21,31} = 8.6 \times 10^{-5}, 2.5 \times 10^{-3}$ eV^2, $\sin^2 2\theta_{12,23} = 0.86, 1.0$

* = 0-3 GeV ** = 0-5 GeV, 1 MW. 10^7s = 5.2×10^{20} POT at 120 GeV, 1yr = 2×10^7s

100kT effective mass is MINIMUM